Basic Electrical Circuits
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Lecture - 15
Opamp, Ideal Opamp Circuits
Non-inverting and inverting Amplifiers
Ensuring that the Opamp has Negative Feedback

Hello everyone, welcome to lecture fourteen of basic electrical circuits. In the previous two lectures we looked at two port parameters how to calculate them for different kinds of circuit. So, you should now be able to calculate two port parameters of any resistive circuits or any linear circuit actually. If you have a purely resistive circuit because of reciprocity there will always be some relationship between parameter 2 1, and parameter 1 2. Now, in this lecture what we will do is go to different topic namely that of op amps or operational amplifiers, which are a very, very useful circuit block in designing, I mean they are used in designing various kinds of electrical circuits.

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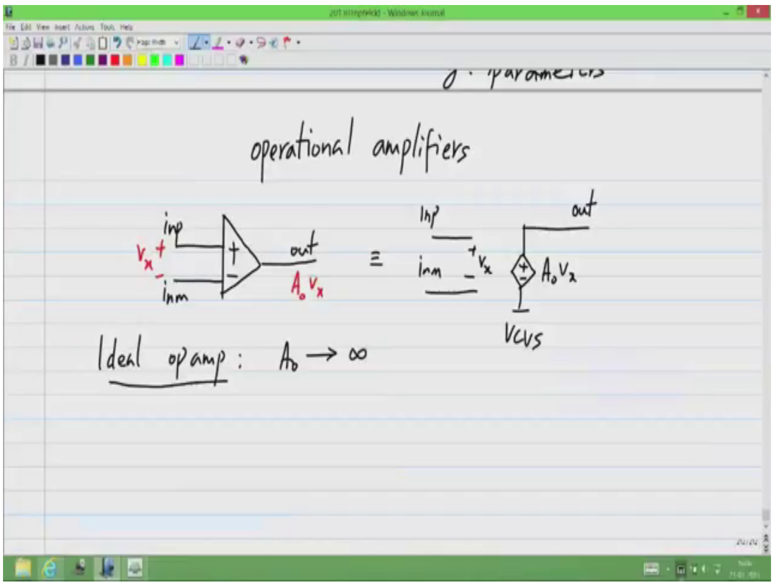

Now, what is an operational amplifier? It is just a voltage controlled voltage source and because it is a block, that used so often it has a symbol of its own which is given by this, this is clearly equivalent to… I will call this in p for positive inputs, and in m for negative input and output, this is equivalent to in p and in m and a voltage controlled voltage source. What does the voltage controlled voltage source give out, it gives a voltage proportional to this and it is multiplied by a very large gain a naught times V x. So, the output voltage here will be a naught times V x, where V x is this voltage measured with this polarity, so this is an operational amplifier.

In this course in particular, we will not worry too much about the internal details of op amp or any non ideal feature. We will be dealing with mostly what will be an ideal op amp and what is an ideal op amp an ideal op amp is one in which a naught tends to infinity. We will later see why this is a very useful property this is any question, so far I just defined op amp as a voltage controlled voltage source. Now, what we will do is to look at second techniques of circuit analysis when op amps are present.

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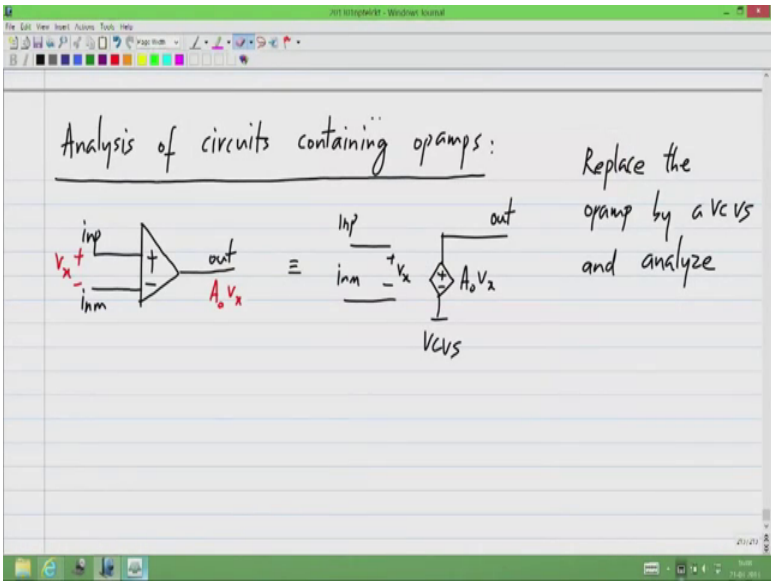

Now, because an op amp is a voltage controlled voltage source, you can simply replace V c V s of appropriate gain and then use it, so this is suddenly possible, now what we want to do is to see in case an ideal op amp if a simpler method of analysis can be found.

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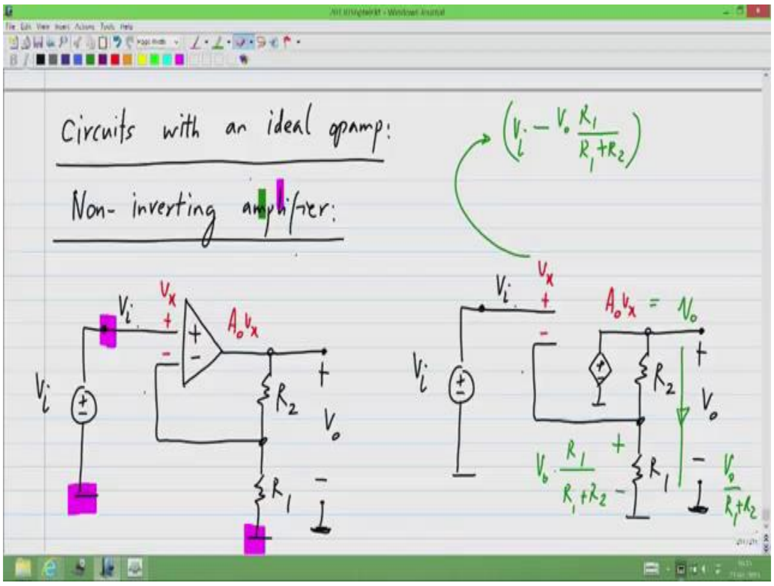

Now, for this I am going to take a circuit, example of an example of a circuit that uses op amps and that turns out to be an amplifier a kind of amplifier, which is used very often its known as a non inverting amplifier. The circuit for that is given by something like this, where this is the input voltage, now this symbol means ground and these are all connected together sometimes just to avoid clatter in the schematic. You take the reference part of the circuit, you do not explicitly connect them together, but this means that this is connected to this. Whenever we say that there is a voltage at a node without specifying two nodes, it is implied that it is with respect to reference nodes.

So, V I applied between this node and the reference node and V naught is obtained between the output node and the reference node and let us say this is some resistor r 2 and this is some resistor r 1. Now, first of all let us assume that the op amp is voltage controlled voltage source and analyze this so that you should be able to do this by assuming some voltage V x here. That means that a voltage a naught V x appears over here since this is the first op amp circuit, we are analyzing I am going tore write the circuit with the voltage controlled voltage source.

So, this is a voltage controlled voltage source between V naught and V x, where V x is the voltage between that node and that node is this clear any questions about this circuit itself any questions about this circuit, then please do answer this question.

If the voltage at this node is V naught what the voltage at this node that is at the junction of r 1 and r 2, what is the voltage please try and answer this question. There, voltage at this node if voltage here is V naught, so it is very easy to calculate this the current in these two resistors is the same because this is connected to an open circuit and no current is going there. So, this current here is V naught by r 1 plus r 2, so r 1 and r 2 are in series and the voltage across this is this current times r 1.

So, it is V naught r 1 by r 1 plus r 2, then what is the value of V x that is the voltage between this node which has a voltage of V i and this node which has a voltage of V naught r 1 by r 1 plus r 2. So, V x equals V i minus V naught r 1 by r 1 plus r 2 and here we see that this voltage controlled voltage source is giving a value of a naught V x and that is the actual output voltage V naught. So, we have defined V naught to be the output voltage of op amp which is a naught times V x.

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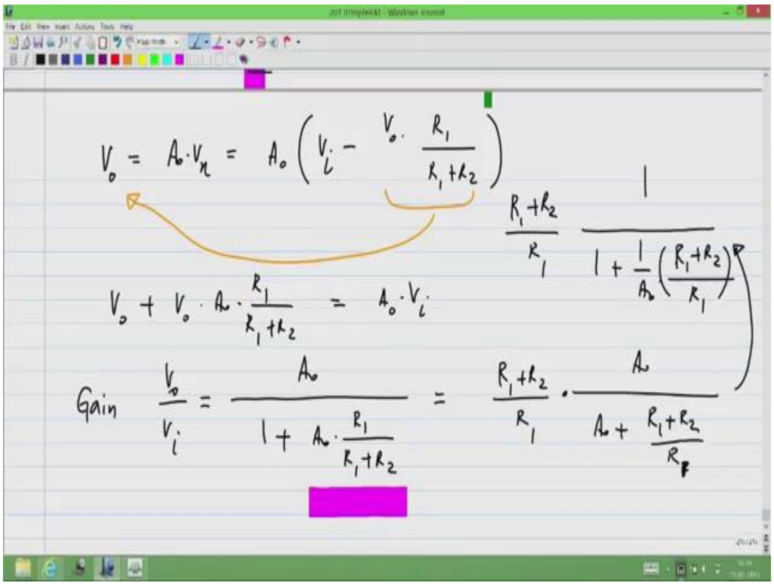

So, from these we can calculate the output voltage, which is a naught times V x which in turn is a naught V i minus V naught r 1 by r 1 plus r 2. So if I take this term to the other side, I will get V naught plus V naught a naught r 1 by r 1 plus r 2 equals a naught times V x. So, the gain of the circuit V naught by V i can be written as a naught a naught divided by 1 plus a naught this ratio of resistors r 1 by r 1 plus r 2. Now, this can be written in number of different ways if I take this term to the numerator, I will get r 1 plus r 2 by r 1 times a naught a naught plus r 1 plus r 2 by r 1.

It can also be written as r 1 plus r 2 divided by r 1 times 1 by 1 plus 1 by a naught r 1 plus r 2 by r 1, so the gain can be written in number of these forms. Like I said earlier, the important thing is the op amp is a voltage controlled voltage source with a gain a naught that is very large a naught tends to infinity, so that is the condition over which we should calculate the gain of the circuit.

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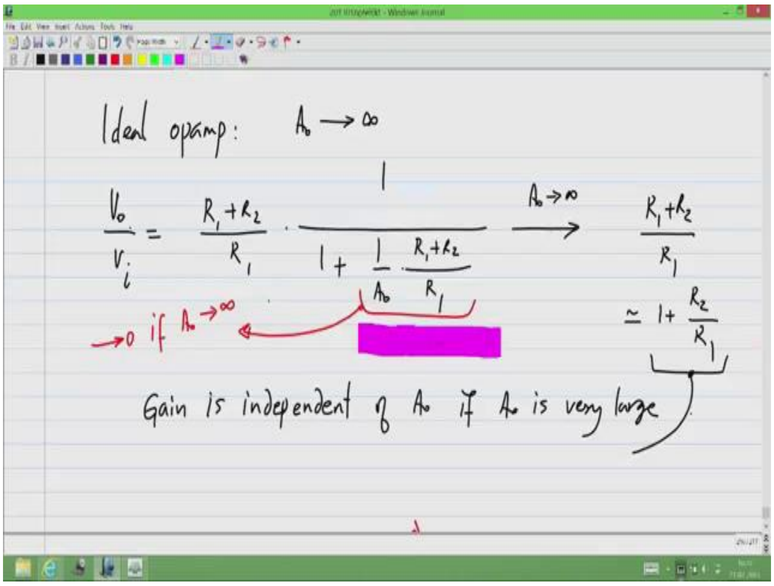

So, as a naught tends to infinity, you can very easily see that this term disappears and the gain becomes r 1 plus r 2 by r 1 or 1 plus r 2 by r 1. So, this is really the virtual using in op amp which is just a voltage controlled voltage source with a very large gain. If the gain is very large, but not infinite, which is what it is going to be in real life the gain V naught by V i will be very close to 1 plus r 2 by r 1, but not exactly 1 plus r 2 by r 1. So, the important thing is that the gain is independent of a naught if a naught is very large, so if a naught is very large the second term in the denominator is much more than 1 and can be ignored completely.

This entire thing becomes one and V naught by V i becomes one plus r 2 by r 1, any questions about this, so as a naught tends to infinity, the gain of the amplifier V naught by V i which is r 1 plus r 2 by r 1 times this entire thing. This is what we derived previously using circuit analysis this becomes r 1 plus r 2 divided by r 1 because this term here this tends to 0 if a naught tends to infinity.

So, even if a naught is infinity, but a very large number, what happens is this term becomes quite small. So, we will have a gain of 1 plus r 2 by r 1, so the point is the gain is independent of a naught if a naught is very large. Now, this is really the reason why op amps are used, it turns out that when you make these controlled sources, these use devices for transistors which you will later encounter in some other course on electronics.

If you rearrange the gain the value of the gain cannot be very accurately set usually, so there is difficulty in setting the value of a accurately. Now, what you do is instead of in order to realize an accurate what you do is you realize a very large gain using transistors. Even if it is not very accurate what happens is that as long as the gain is very large this term disappears and you have a gain that is defined very accurately using resistors, I hope that is clear also, let me copy over this circuit.

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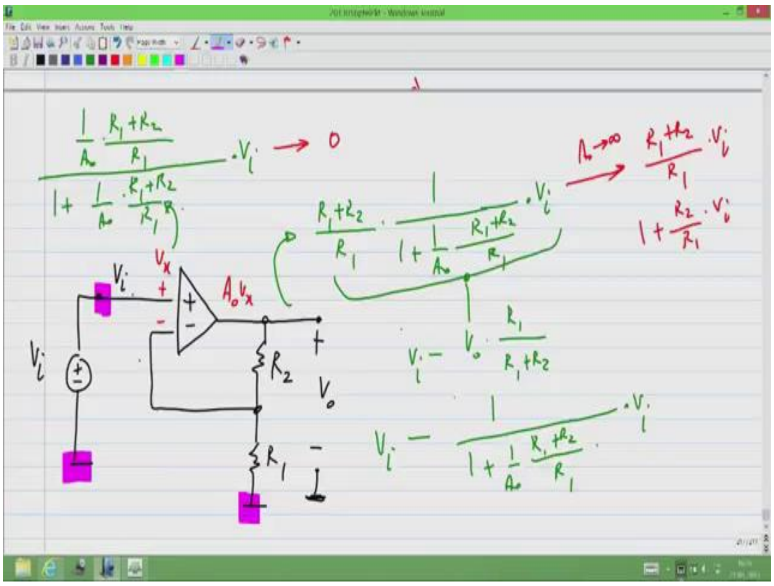

So, the output voltage V naught like I said it is r 1 plus r 2 by r 1 times 1 by 1 plus 1 by a naught r 1 plus r 2 by r 1 times V i that is the gain times V x and this V x. So, if you calculate what was V x V x is nothing but V i minus V naught r 1 by r 1 plus r 2, where V naught is this whole thing. So, it is V i minus 1 by 1 plus 1 over a naught r 1 plus r 2 by r one times V i, so if you evaluate this, this comes out to be 1 by a naught r 1 plus r 2 by r 1 1 plus 1 by a naught r 1 plus r 2 by r 1 times V i.

Now, the point is that as a naught tends to infinity, which really means a very large a naught in practice this becomes r 1 plus r 2 by V i or 1 plus r 2 by r 1 times V i. This becomes zero that is a naught is in the denominator here, so this term becomes zero, so this is the feature of an ideal op amp that as a naught tends to infinity the input voltage of the op amp tends to 0.

Now, it is not exactly 0 for any finite value of a naught, so if a naught is infinite, the value of V x tends to 0, so this gives us more efficient way of finalizing op amp circuits. So, instead of substituting voltage controlled voltage source in place of the op amp that will suddenly work you can directly substitute these two voltages to be equal to be 0, it is a basically a short cut for analyzing op amp circuits, so let us do that.

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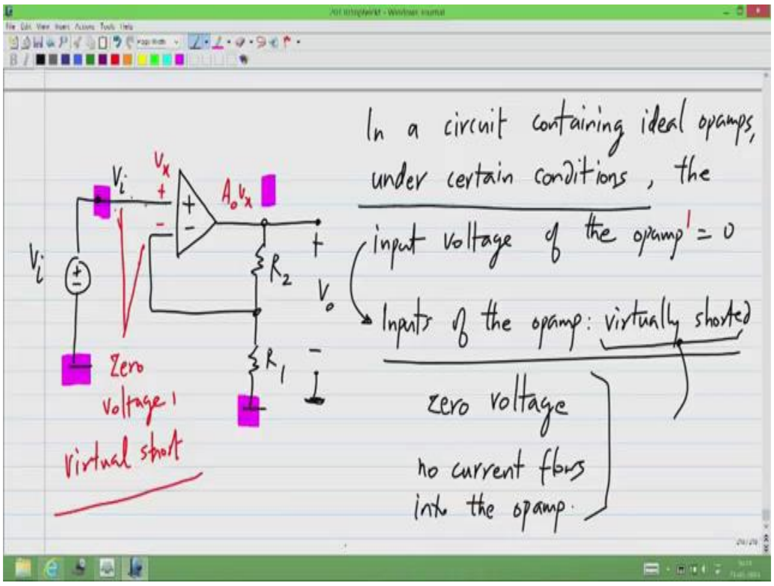

So, it turns out that basically in an ideal op amp, let me see in a circuit containing ideal op amps looks like some of windows shut down. So, in a circuit what I was saying was in a circuit containing ideal op amps under certain conditions I am going to elaborate what they are these conditions are very necessary. The input voltage of the op amp equals 0, so what I mean is that this V x here this will be 0 if the op amp is ideal. So, this gives us the short cut for analyzing circuits with ideal op amps, so this business of V x being equal to 0, this is known as a virtual short circuit. So, if you have a short circuit the voltage between, if you have a short circuit between two points the voltage will be 0 and any current can flow through the short circuit.

In this case it is slightly different the voltage between these two points will be 0, but no current will flow between them. So, no current will go into the op amp and come back to the wire so that is why it is known as virtual short circuit this basically is also called as the inputs of the op amp being virtually shorted each other.

So, virtually shorted means that this means that the voltage across them is 0, but no current flows into the op amp, it is not a short circuit, it is just a virtual short circuit. So, let us say how this idea simplifies the analysis of op amp circuit, so I will take the same circuit instead of using the voltage controlled voltage source in place of the op amp, I will just use the virtual short circuit and figure out what the output is going to be.

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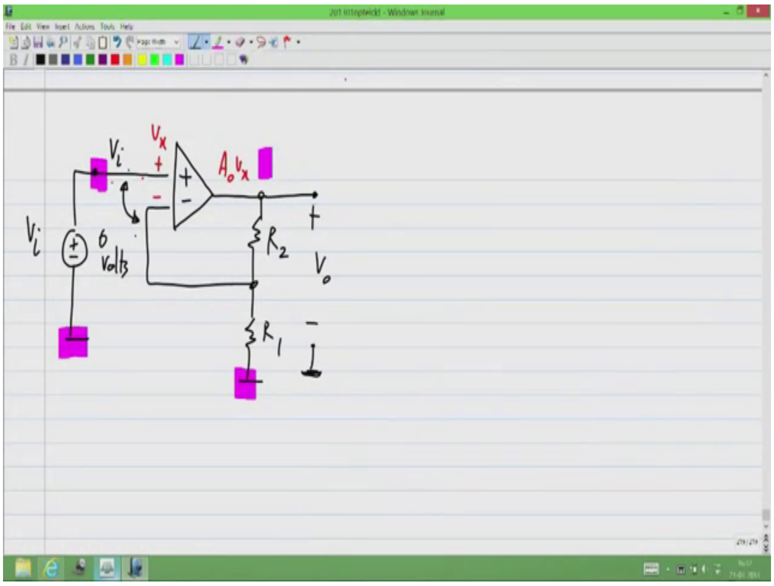

So, virtual short circuit what it says is that between these two, we have 0 volts, so this means that is the screen not visible is there a problem. So, there is a question why current does not flow in case of virtual short circuit, now the voltage between these two is 0 because the gain is infinity not because a wire is connecting them.

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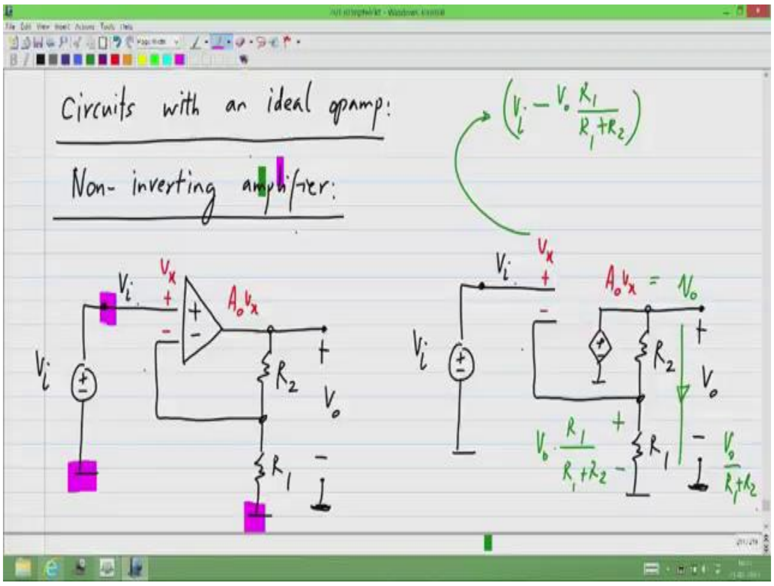

If you go back to the picture with the controlled source, it becomes even clearer you see that this wire is going nowhere, there is no path for current to flow. Similarly in this there is no path for the currents to flow, but there is virtual short between these two because V x tends to 0 as a naught tends to infinity. So, this is what I mean is a virtual short, there is no wire between these two in that case a current can flow here current cannot flow into this wire regardless of the value of a naught right this wire is just an open circuit. Here, no current will flow into the op amp, but because a naught tends to Infinity this voltage becomes 0, so that why it is a virtual short not a real short.

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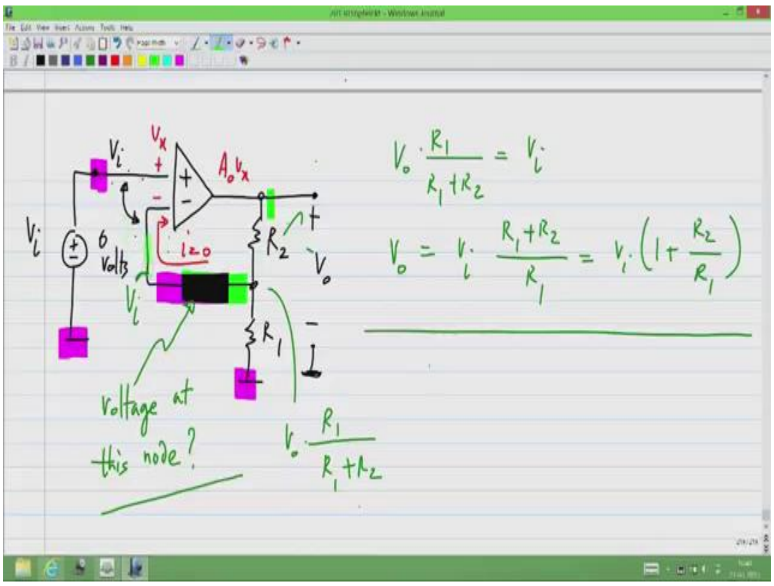

Now, let us try to re analyze this circuit using the concept of the virtual short, so if there is 0 volt between these two nodes what is the voltage at this node, what is the voltage at that node. So, if there is a virtual short between the inputs of the op amp what is the voltage at this highlighted I will write it again this node. So, there is a question here how is the gain infinite that is the assumption we are using, we will design the op amp to have a gain of infinity in reality. Of course, you will never be able to reach infinity you will reach a very large number, so you can think this infinity as an approximation to a gain that is very large.

So, what is the voltage here at the highlighted node in terms of the input voltage V i, I think there is problem here, but others are probably able to see the writing, you are not able to see the writing how about others. Anybody else has this problem of not being able to see the writing, I think maybe the problem is on your side, perhaps you can quickly close the browser and reopen it.

So, now hopefully the audio is also clear, now what I was asking what is the voltage at this node in terms of V i. So, if this is a virtual short that is these two have the same voltage it means that clearly this node also has to have the voltage of V i, so the voltage here equals V i. Now, we also saw earlier that the current going here this way is 0, so clearly if there is V naught here, the voltage at this point given by voltage divided formula is V naught r 1 by r 1 plus r 2.

So, what I have done is to determine the voltage of this through two different ways one is by observing this is a virtual short it has to be equal to V i and another one is observing that the current here is 0. So, if this point i V naught this point has to be V naught times r 1 by r 1 plus r 2, so clearly whatever we derive for the same node from two different methods has to be equal to each other. So, that means that V naught times r 1 by r 1 plus r 2 equals V i or V naught equals V i times r 1 plus r 2 by r 1 or V i times 1 plus r 2 by r 1.

So, I hope that this part is clear in this case I did not assume that the op amp was virtual sorry voltage controlled voltage source with a gain of a naught I assumed that op amp offers a virtual short between its inputs. So, when it is a virtual short you can immediately determine that the voltage here is V i, it has to be equal to what you determine from the output which V naught times r 1 by r 1 plus r 2. So, by manipulating this, we see that the output is input times some gain which is 1 plus r 2 by r 1.

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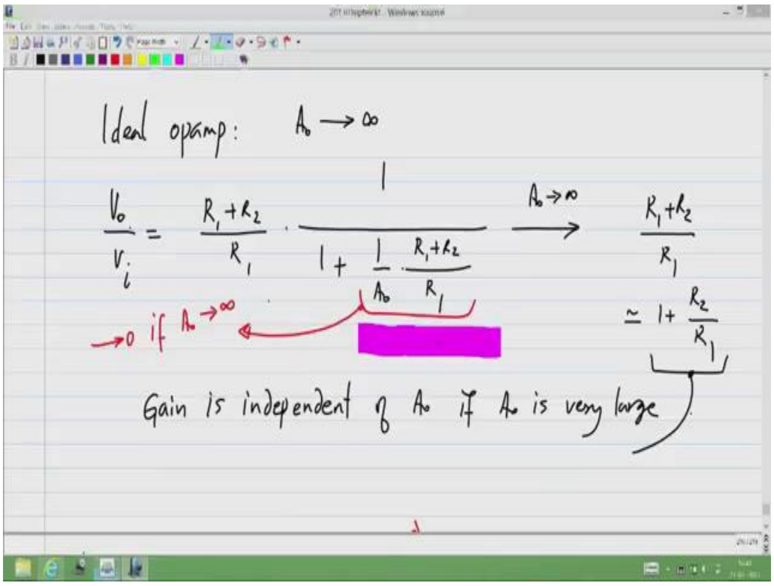

That 1 plus r 2 by r 1 is exactly the gain we derived when a naught is very large, so when the op amp is ideal you can use this short cut to analyze the circuit, any questions? An op amp is nothing but a voltage controlled voltage source with a very large gain, the whole point is you make the gain very large, it does not have to be precise, but the gain value will not depend very much on gain. So, for instance you can make the gain 10,000, let us say for various reason usually the temperature change and so on the gain will change. It could change all the way from 10,000 to 15,000 or 5,000, it is a very big change, but as long as a naught is very large the gain will not change all that much, any questions, then let us move on with the lecture.

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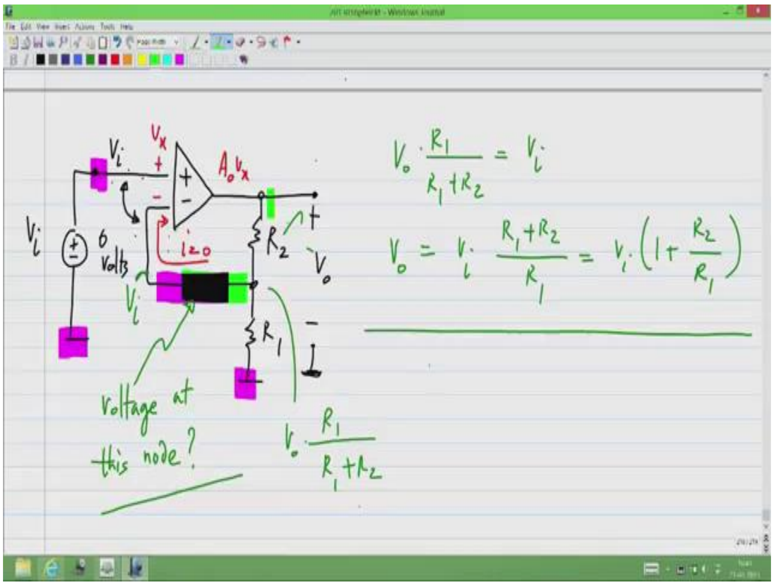

So, which part is not clearly understood, so which would you like me to explain again we will move on with the lecture.

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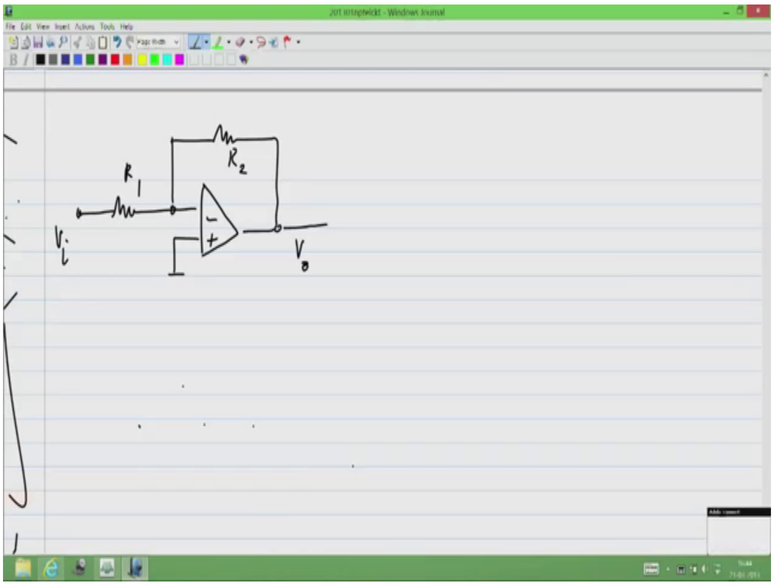

Now, we can take another op amp circuit, let me do that.

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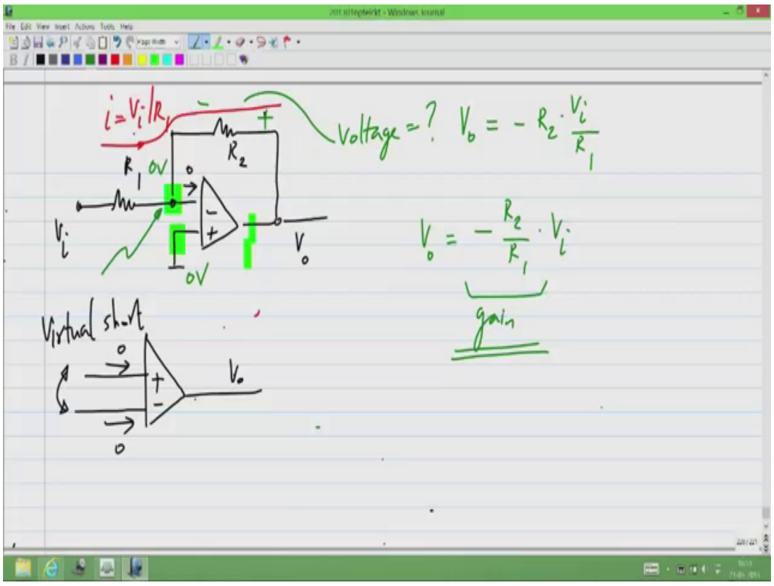

So, let us see if it becomes clear after we do this circuit, so this is another circuit using op amps and now between these two nodes, there is a virtual short. So, that means that so this point is at 0 volts, so this point is also at 0 volts, so remember in case of an ideal op amp there is a virtual short between these two points, but no current flows into the op amp. So, in this case also no current flows into the op amp now because this is at 0 volts what is the current through r 1, please try to answer this, what is the current through r 1, so clearly it is equal to V i by r 1.

So, we have V i across the resistor and the current is V i by r 1, now I will not be able to take any questions via audio any questions you have please type it into the chat window. Now, this current it can go either the op amp or r 2, we know that no current goes into the op amp. So, it will go into r 2, now what is the voltage drop across r 2 in this polarity, so let me mark that here what is that voltage across r 2 it is equal to V 0, but in terms of V I, what is the voltage, no voltage is not infinite. On the right side, you have V naught on the left side we have 0 volts, so the voltage across it is definitely V naught, but you also know the current that is flowing through it. So, you can try and figure out the voltage across it what is it that is correct, so clearly this current is flowing that way, so this current times r two will be the voltage drop with the left side positive, but here I have defined it with the right side positive.

So, the voltage equals V naught is minus r 2 times V i by r 1 or V naught is minus r 2 by r 1 times V i, so this is the gain and because this is r 1 amplifier that is classic amplifier and we analyzed it by assuming the virtual short between the inputs of the op amp. Any questions about this circuit, so there is a question is there any chance to change the gain of an op amp by putting a resistor in the non inverting terminal. Now, we will see the condition under which the op amp will behave like virtual short the op amp inputs. Also, just to be precise it is not the gain of the op amp that is changing the gain of the op amp is a naught which is assumed to be 10 into infinity the gain of the circuit which is built using the op amp.

So, the gain of the op amp which is a naught is fixed, there is another question why feedback is used in op amps now it is particular type of feedback negative feedback it will create virtual short. Now, in this course we will not go into the course of negative feedback I will just tell you there has to be negative feedback and how to find it, how to find whether there is negative feedback or not. Now, what I meant was the answer to earlier questions, now I will go through the conditions under which the op amp input will behave like avirtual short.

Now, the resistor could be at the non inverting terminal also, but we have to see it depends on the topology. There are numerous topologies of op amp circuits and some of them have only to the inverting terminal some of them to both inverting and non-inverting terminals. Also, just to be precise it is not the gain of the op amp that is being changed it is the gain of the overall circuit the gain of the op amp is a naught and it is fixed and the gain of an ideal op amp is infinity.

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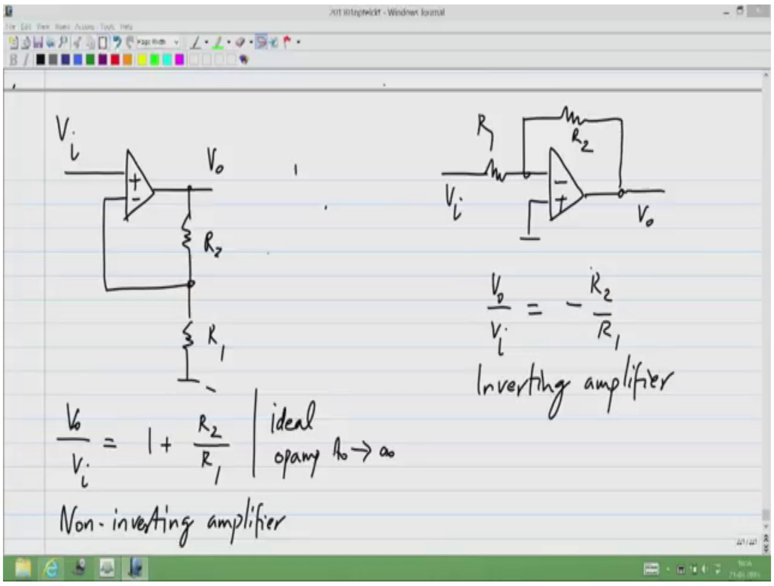

So, we have looked at two op amp circuits and in this circuit V naught by V i equals 1 plus r 2 by r 1 and we have this other circuit V naught by V i equals minus r 2 by r 1. Now, because the gain of the circuit on the left side is positive, it is known as a non-inverting amplifier and because the gain of the circuit on the right side is negative this is known as an inverting amplifier. So, these are classic op amp circuits and by the way these are true when the op amp is ideal which means a naught tends to infinity if a naught is less that infinity.

Then, a naught will appear in the gain expression of the gain, but as long as a naught is very large the gain will approximately be equal to 1 plus r 2 by r 1. Similarly, the gain of inverting amplifier will be minus r 2 by r 1, in fact I encourage you to replace the op amp by the controlled source in the inverting amplifier and calculate the gain, so you can take it up as an exercise.

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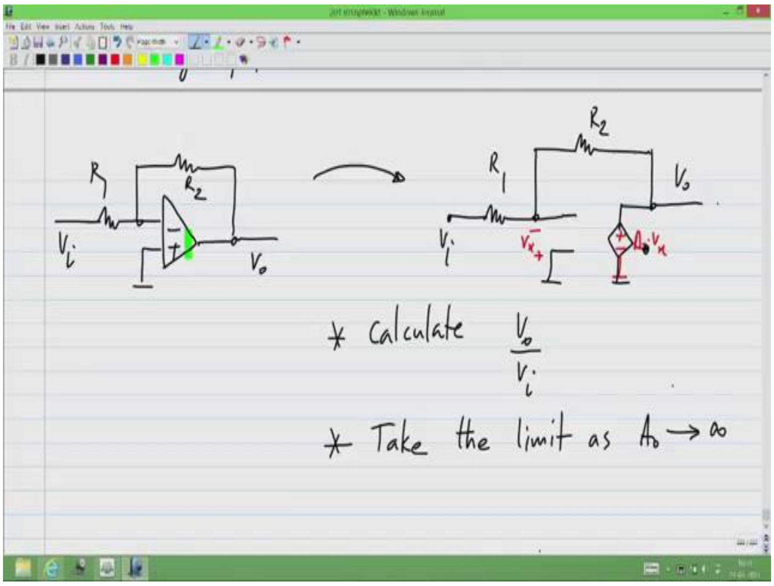

So, if you replace this op amp with voltage controlled voltage source because pluses on the bottom minuses on the top V x and this will be a naught times V x with this polarity. So, please analyze this circuit, it will be general practice for circuit analysis, then you take the limit for a naught tending to infinity and you should get the same answer as what you got for assuming the op amp input as virtual short. Now, there is another question what is the difference between neutral and grounding, now this is completely out of the scope of the syllabus of basic electrical circuits. This has to do with safety and issues like that grounding is the ground wire is something like the ground wire used in the household supply is wire that is actually connected to the earth.

So, that and the neutral is the neutral is something that is connected to the earth, there should be a small voltage difference between these two so that you do not have a shock when you accidently touch electrical equipment and so on. We cannot deal with this in detail here, so you will have to go through other courses to understand this, but the concept is simple and you can also refer to some standard textbooks to find out, now I said that, so basically the rules for analyzing the ideal op amp circuits can be written down.

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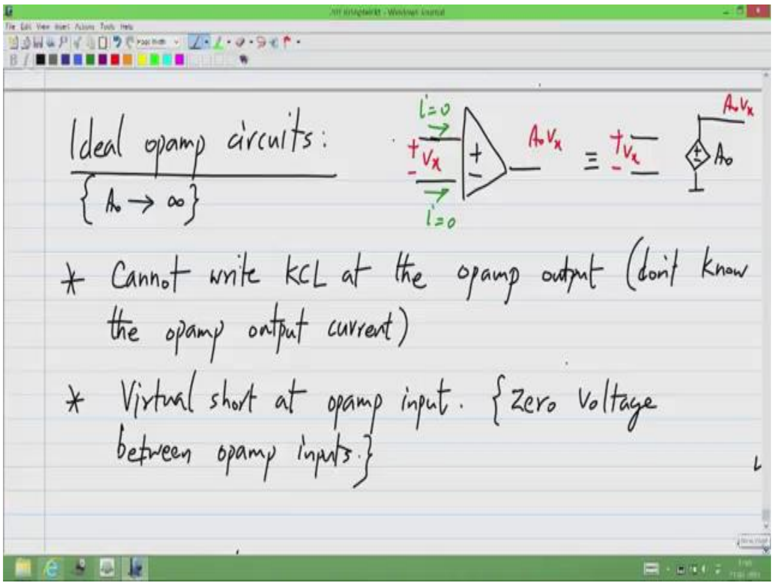

First of all, what is an ideal op amp this is an op amp it is a voltage controlled voltage source with a gain a naught and the current going into the op amp terminals is 0 and an ideal op amp means that the gain tends to infinity. So, to analyse ideal op amp circuits, you can use the methods we used earlier, but you cannot write KCL at the op amp output. This is because you do not know how much current is going into the op amp instead what you can do is to write the virtual short equation at the op amp input. So, that is the two inputs of the op amp have 0 voltage between them, now I said that this virtual short condition is true only under certain conditions, so virtual short condition.

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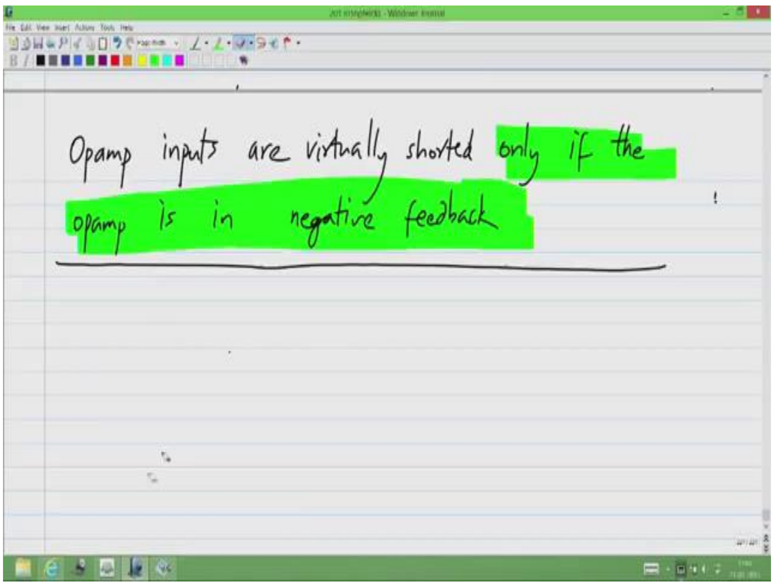

Let me write it as op amp inputs are virtually shorted under certain conditions and that condition is only if the op amp is in negative feedback. So, this is a very important condition, you cannot assume that the op amp inputs are virtually shorted in any circuit in every circuit the op amp has to be in negative feedback. In order for the op amp inputs to be virtually shorted, I will tell you what this means I will tell by taking two examples, let me take the non inverting amplifier first, so let me take this circuit.

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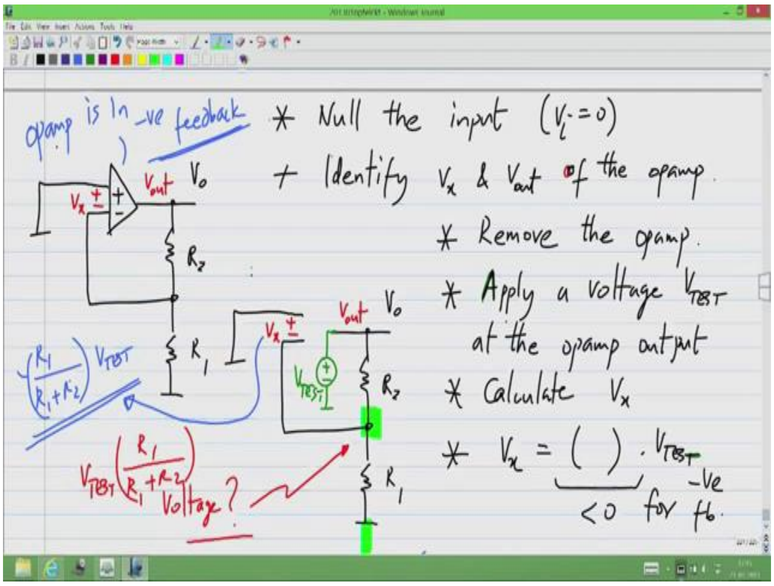

Now, what I will do is I will null the input that is I will set V i equal to 0, so that means that I basically short circuit this to ground. Then, I will identify the input voltage V x and the output voltage V naught of the op amp in this case V naught is the output voltage of the circuit also. As a procedure, you just identify V x as the appropriate polarity that is plus here and minus there, let me call this V out this is really the output of the op amp in this particular circuit it is also the output of the circuit. You can have more than one op amp in a circuit V x and V out of the op amp, so then what you do is you just remove the op amp.

Let us say I remove this op amp and then you apply test voltage to wherever the op amp output was this is V test I just connected that I removed the op amp. Instead of the op amp output wherever the output was I connect the voltage source V test, apply a voltage test voltage V test at the op amp output.

Then, you calculate V x, V x is already been identified, it is basically the input of the op amp when the op amp was present in the circuit. Now, V x will be because this is a linear circuit and in general any such circuit you take will be linear circuit V x will be some number times V test and this number has to be negative for the op amp to be negative feedback, this is the procedure. Let me go over it once again I first null the input because when I say the op amp is in feedback, I am only interested in how much of the op amp's output comes back to the input that is the meaning of feedback. If no part of the output comes back to the input there is no feedback at all, so if some part of it comes back to the input there is feedback that is what I am trying to determine here.

So, that is why I am not interested in the input voltage itself the input voltage to the circuit I am only interested in how much of the op amp's output comes back to the input. So, I first null the input in this case that means that I set the input voltage to 0, that is why I short the input to ground. Then, I identify the input and output voltage of the op amp that is V x with this polarity that is important and we notice the output of the op amp with respect to the ground. Then, I just remove the op amp and instead of the op amp I connect the voltage source V test wherever the output voltage was. So, then I calculate V x in the new circuit with the op amp removed and the new voltage source in separate.

So, this is just for testing the circuit V test is some arbitrary voltage, now because this is a linear circuit V x will be some number times V test it has to be, so V x will be some number times V test and that number has to be smaller than 0. That is the number has to be negative the multiplying factor if it is negative then this op amp in the original circuit is in negative feedback. So, what it means is V x has a contribution due to V out that we described by applying this V test in place of V out. Now, the contribution is negative if this number is negative.

So, that is the meaning of the op amp being in negative feedback, we will test it out for this circuit as I mentioned earlier I am unable to take questions via audio, please ask your questions on the chat window is the procedure clear. So, let us try it for this circuit that is I have removed the op amp identifying V x and V out, then I removed the op amp and I applied V test here.

So, please now calculate the voltage that appears here what is the voltage that appears there, please let me know the answer the voltage that appears at this node see V x is the difference between this upper node and this one and this node is the ground that is 0 volts. So, I have to find the voltage of this node, so what is the voltage that appears there, what is the voltage that appears there at the junction of r 1 r 2 due to V test, clearly V test is applied to this voltage divider. So, this voltage is nothing but V test r one by r 1 plus r 2, the voltage divider times V test, so what is the value of V x, then what is the value of V x please mind the polarity of V x.

So, it is not minus V test, but minus of the voltage that appears here, so V x will be minus V test. Now, let me write it like this minus r 1 by r 1 plus r 2 times V test, so it is some number times V test and that number is negative. By the way, there was some answer saying both will be in the same potential I am not sure which both is being referred to these two. If you are talking about these this node and that node then certainly not be in the same potential in this circuit, they will be at the same potential in the circuit when the op amp is present.

The op amp has negative feedback this circuit does not have the op amp, so this and that will certainly not be at the same potential. So, the voltage V x is minus r 1 by r 1 plus r 2 times V test, so it is a negative number times V test, so this op amp here, this op amp is in negative feedback. So, the reason that is very important is that only with negative feedback you will get the virtual short and the desired function you want to implement. So, there is another question what are the assumptions made in the ideal op amp the assumptions made are simply that a naught equals infinity that will take care of everything else.

Now, here if you look at it, I defined and assigned a naught as infinity, I also said I equals 0, now actually that is not a separate assumption if you take any circuit with the op amp even if there is a resistance between these two points if a naught becomes infinity it becomes an ideal op amp. Now, for simplicity what I will assume is it is a voltage controlled voltage source that is no current is flowing here that this is a voltage controlled voltage source and the value of a naught is infinite. So, I hope that is clear, the essential assumption for an ideal op amp is that the gain has to be infinite, now the reason this is important is the following, so let me copy over this circuit again.

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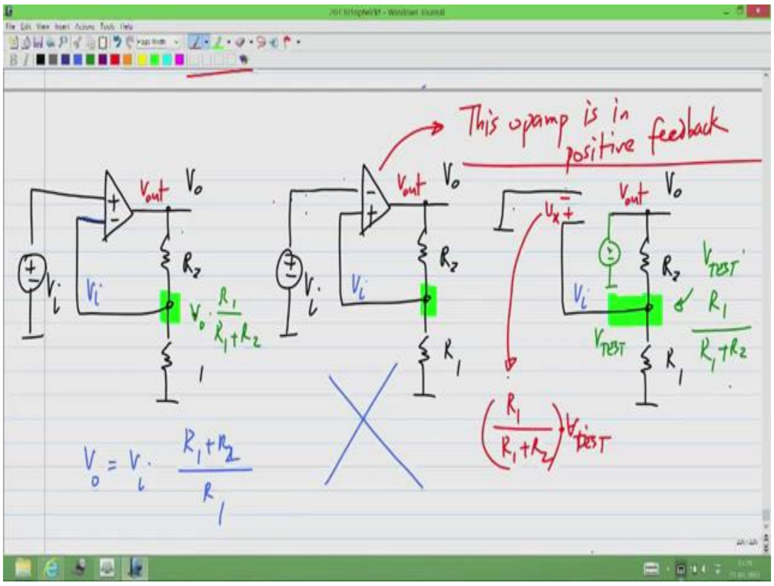

So, let me put the input back here, now in this case in the second case let me do this let me make the lower one plus and the upper one minus. Now, the point is that if you calculate this voltage from the output side this is V naught and this point will be V naught times r 1 by r 1 plus r 2 here. Also, it will be V naught times r 1 by r 1 plus r 2, so they will be exactly the same as each other obviously also if I assume the ideal op amp and say that it is virtually shorted, this voltage is same as that voltage. So, that means that form the input side this will be V i and here also it will be V i if I assume that there is a virtual short between these two terminals.

So, wherever I use the circuit on left side or the circuit on the right side, I get the same relationship V i equals V naught times r 1 by r 1 plus r 2 or V naught equals V i times r 1 plus r 2 by r 1. So, if I blindly apply the virtual short concept that, what I will get, but this circuit is very different from this. In fact, it will not work at all, so this circuit will not work and the reason is that we can look at the feedback in this particular circuit. So, what I will do is let me copy over this and I have to null the input, I will do that I want to see whether it is in negative feedback. I null the input and I identify the input and the output of the op amp remember that V x is defined like this because plus sign is on the bottom side and i remove the op amp and I apply V test.

So, what happens at this point I will get V test times r 1 by r 1 plus r 2 and if you calculate the value of V x in this circuit it is equal to the voltage at this node because of the polarity whereas, previously in this circuit V x was negative of the voltage here. So, the voltage here was V naught r 1 by r 1 plus r 2 that part is same now also, but this V x was negative of that whereas, now V x is equal to r 1 by r 1 plus r 2 times V test. So, it is a positive number times V test so that means that in this circuit I mean this op amp is in positive feedback.

So, if it is in positive feedback, then this virtual short assumption simply does not apply. So, it is an important thing the virtual short concept provides an easy way to analyze a circuit containing an ideal op amp. It has to be applied with care you have to check separately that the op amp is in negative feedback and the way to do that is given by series of text I displayed earlier.

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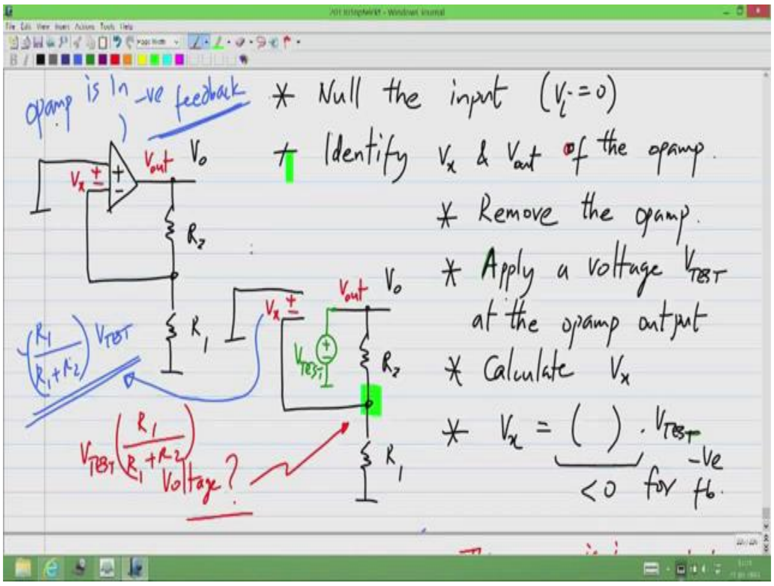

You null the input because this is nothing to with input feedback refers to what fraction of the op amp output comes back to its own input identify V x and V out of the op amp whichever op amp you want to find the feedback. Then, you remove the op amp in place of the op amp’s output you apply a test voltage V test and then now you have a basic linear circuit which you can analyze and find the input the input voltage V x of the op amp.

So, this V x of the op amp will by some number times V test and that number if it is smaller than 0, the op amp is in negative feedback, then the virtual short assumption I valid if it is greater than 0, it is in positive feedback. You cannot assume the virtual short if it is equal to zero also there is no feedback at all and the virtual short is not valid, so there is another question what will happen if we use positive feedback. So, that again we will not get into in this course what is going to happen is that there will be no virtual short that is for sure and the way we have defined it the op amp is a voltage controlled voltage source.

The output voltage can be any value it depends on the input voltage in reality when you make a real op amp the output of the op amp will have certain limits, it will depend on the supply if you op amp from 10 volts output cannot go beyond 10 volts and so on. So, it will end up blowing and getting stuck to either the maximum limit or minimum limit on its output voltage, so that is what is going to happen to the op amp if you use it in positive feedback, any other questions, so similarly if we look at the inverting amplifier.

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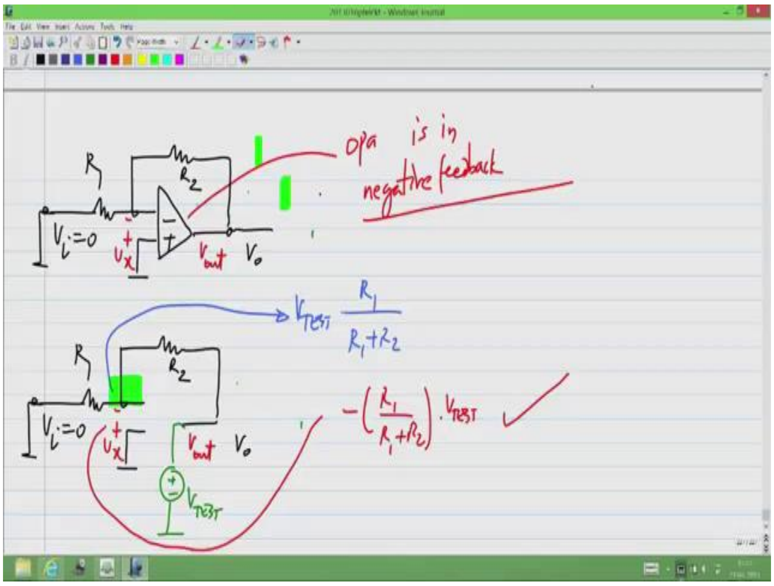

Again, we can apply the same algorithm, so first I null the input that means that I short this to ground that is V i equal to 0, so then I remove the op amp apply V test, sorry I also had to identify let me remove this before coming to this step. I had to identify the input voltage V x and the output voltage V out of the op amp, then I remove the op amp and apply V test to the output of the op amp.

So, what is the voltage that appears here in this circuit what is the voltage that appears at this node please find this what the voltage that appears there is, what it appears there is V test times r 1 by r 1 plus r 2. So, the value of V x is the negative of this because of it polarity, so this will be minus r 1 by r 1 plus r 2 times V test, so this means that this is the op amp here is in negative feedback. Now, if I interchange the plus and minus signs of the op amp, it will be in positive feedback and what we discussed so far will not be applicable anymore.

So, any questions about op amp circuits what we learned was two popular circuits of the op amp which are the inverting amplifier and non-inverting amplifier and also in an op amp the op amp is voltage controlled voltage source with a very large gain. So, if the gain is very large then the gain of the circuit the gain of the amplifier will not depend so much on the op amp’s gain. So, there are two gains that we talked about here the V naught by V i of this circuit the amplifier we make and also the gain of the op amp that is the gain of the voltage controlled voltage source which is inside the op amp. So, as long as it is very large the gain of the circuit does not depend upon this value a naught.

An ideal op amp is where this a naught goes to infinity that is the largest gain you can possibly have in that case the analysis of op amp circuits becomes quite simple. In that case, you can assume that the two inputs of the op amp circuit are virtually shorted it is called virtually short because there is no wire that can conduct current between these two the two voltage are equal, but no current flows between them. So, that is why it is called virtual short and using this virtual short concept you can easily analyze op amp circuits.

One thing you have to be very careful about is that the op amp has to be in negative feedback for you to be able to apply this virtual short concept. Otherwise, you simply cannot use that, so that means that the op amp has to be hooked up with the correct polarity I have shown the circuits with the correct polarity, I have also showed you what happens if you have the wrong polarity.

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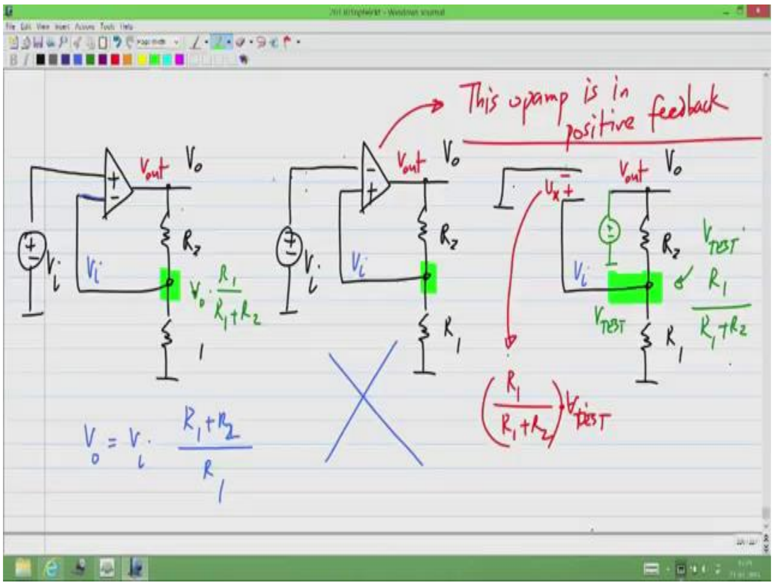

In this case, if you have the upper one to be minus the lower one to be plus then this op amp is in positive feedback and you cannot assume that these two are virtual shorts. So, if you use that you will get the same formula as before for V naught, but that will be completely wrong, so is this clear any other questions.

So, there is a suggestion for books on this topic I will try to find, but personally no book deals with the negative feedback explicitly like this, but just for general op amp circuits and ideal op amp circuits. There are many books book by linear circuit analysis, you can use that and there is a book on op amps, the book is dedicated to op amps, it is full of circuits you can use that as well.

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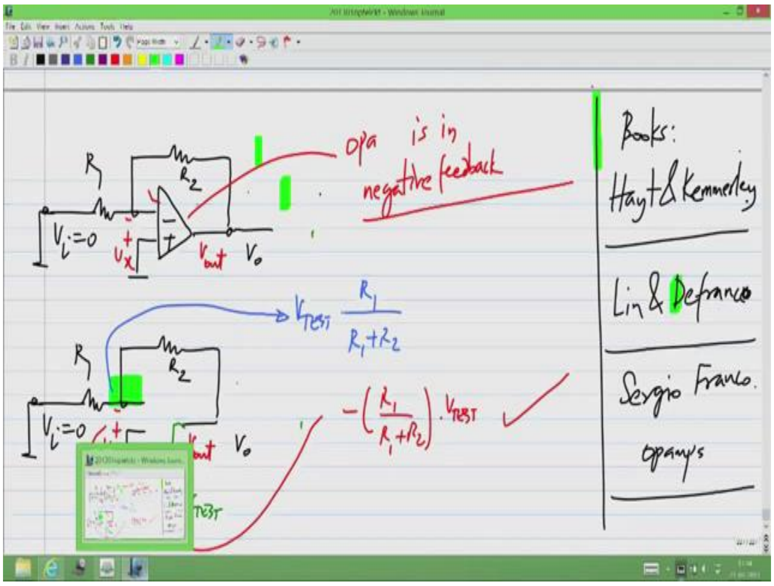

There is Sergio Franco on op amps, there is an answer 0 volt, I am not sure to which question this is the answer, the next question is if the voltage is 0 on op amp why are we calculating V x. Now, this is the way to calculate whether the op amp is in negative feedback or not, we are not trying to find out what the output voltage is in terms of the input voltage. We are trying to find out if the op amp has negative feedback around it, so it is not that the voltage on the op amp is 0 whatever that means you null the input source, you set V i equal to 0. You remove the op amp you apply this V test basically all you are trying to find out is the voltage here depends on the op amp output because of this connection r two this feedback connection.

Now, you will have to find out whether V x is related with a negative factor to V out or positive factor that is what you are trying to find out, so how much of the op amp's output affects its own input that is the key to feedback. If the op amp's output is not connecting back to its input there is no feedback at all, if I remove this r 2, then here whatever the value of V test value of V x will be 0, then there is no feedback, but this V test influences V x. That means when the op amp is really there then the op amp's output influences its input, you are trying to find it whether its positive feedback or negative feedback I hope that its clear, which book is easy to understand.

I think you have to read some book and then see whether it is easy for you, so it depends on individual taste the first two books are more general circuit analysis. There is one chapter on op amps, whereas the third book is completely about op amps, so all the aspects of the circuit analysis in dependent sources and so on. The first two books are quite good they have a lot of examples and problems at the end of the chapter, then if there are no more questions, I will see you next week I will end the lecture here, bye.